

ART. XVIII.—*Obsidianites—Their Origin from a
Chemical Standpoint.*

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This paper is written in order to bring together the various analyses which have been made of obsidianites and allied substances, and an attempt is made to show what bearing the chemical composition has on the various hypotheses that have been advanced to account for the origin of these interesting objects. There is no necessity for any description of form, or mode of occurrence, of obsidianites, as this part of the subject has been exhaustively treated by Mr. Walcott,¹ who also gives numerous illustrations of the different types found.

CHEMICAL COMPOSITION.

In searching through the literature on obsidianites, I have only succeeded in finding the records of seven complete analyses, and one of these, that of a Victorian specimen, published in the Melbourne Exhibition Catalogue, 1866, and quoted by Mr. Walcott, is much too inaccurate for purposes of classification, and is omitted from the following table of analyses. Mr. Walcott kindly supplied me with a broken obsidianite from near Mt. Elephant, Victoria, and this has been carefully analysed by Mr. G. Ampt, B.Sc., in the Chemical Laboratory of the University. Mr. Ampt has also analysed the material of three small buttons from near Hamilton, Victoria. These specimens were obtained for me by Professor Spencer, through Mr. C. French. A third analysis has been made by Mr. Ampt of a button from Lake Eyre District, South Australia. This button was one of

a number presented by Mr. Kemp, of Peake Station, Lake Eyre District, to the members of Professor Gregory's party during their trip to that area. Besides making accurate determinations of the main constituents of the obsidianites, Mr. Ampt has made an exhaustive determination of the rarer constituents, and must be congratulated on the high standard of his analytical work.

Several writers have referred to the chemical composition of obsidianites. Mr. Walcott,¹ while pointing out that the analyses he quotes show that the glasses belong rather to the trachytic than to the rhyolitic series, adds:—"It is to be regretted that so little has been done in their chemical examination, because it is quite possible that each occurrence may present features in common, while differing from those of others. We should also be able to ascertain whether any divergence from ordinary obsidian can be established." Mr. Simpson,² after quoting an analysis, states:—"In chemical composition this specimen agrees with those found in Victoria, New South Wales, and Central South Australia, as well as from Billiton and other islands of the East Indies. It is identical with that of ordinary obsidian of undoubted volcanic origin." Referring³ to the analyses of obsidianites from the Upper Weld and Pieman, Dr. Hillebrand says:—"The analyses revealed compositions which, while not absolutely unique in petrographic literature, are seemingly approached but once or twice. Very unusual is the molecular preponderance of potash over soda in a rock of this character so high in lime."

In dealing with glasses such as the obsidianites, the microscope gives us no help in determining the composition, so that we must depend entirely on chemical analyses. It should, however, be noted that, having obtained a good series of analyses, the careful determination of the specific gravity of a specimen should give an approximate idea of its composition. It is impossible to properly compare analyses, simply stated as percentages of oxides, and the use of some such scheme of classification as that worked out by Messrs. Cross, Iddings,

1 Proc. Roy. Soc. Victoria, vol. xi, n.s., pt. I., 1898, p. 31.

2 Bull. No. 6. West Aust. Geol. Survey, p. 79.

3 Annual Rep. of the Sec. for Mines, Tasmania, 1905, p. 21.

Pirsson and Washington¹ is absolutely necessary in order to find the true relationship between glasses, such as the obsidianites.

The analyses of the obsidianites are as follows:—

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO ₂ -	72.39	76.25	77.72	71.22	70.62	71.65	64.68	69.80	73.59
Al ₂ O ₃ -	13.12	11.30	9.97	13.52	13.48	11.96	16.80	15.02	12.35
Fe ₂ O ₃ -	.42	.35	.32	.77	.85	6.62	6.57	.40	.38
FeO -	4.48	3.88	3.75	5.30	4.44	n. d.	1.01	4.65	3.79
MgO -	1.87	1.48	1.59	2.38	2.42	2.09	2.50	2.47	1.80
CaO -	3.17	2.60	2.40	3.52	3.09	3.03	3.88	3.20	3.76
Na ₂ O -	1.54	1.23	1.29	1.48	1.27	1.76	tr.	1.29	1.03
K ₂ O -	1.92	1.82	1.96	2.28	2.22	2.40	4.01	2.56	1.93
H ₂ O +	.11	.32	.15		.01			n.d.	.27
H ₂ O -	.02	.02	.04		.06			n.d.	.53
CO ₂ -	nil	nil	nil		nil				
TiO ₂ -	.76	.65	.86		.90			.80	.70
P ₂ O ₅ -	nil	nil	nil		nil			nil	nil
MnO -	.05	.06	tr.	.28	.42	.16	.20	.18	.15
Li ₂ O -	st. tr.	st. tr.	st. tr.		st. tr.			st. tr.	
SrO -	nil	nil	nil					nil	f. tr.
BaO -	nil	nil	nil					?	f. tr.
Cl ₂ -	nil	nil	nil		tr.				
SO ₃ -	nil	nil	nil		tr.			?	nil
Cr ₂ O ₃ -	?	nil	?						
NiO -	.06	.03	tr.		tr.			?	nil
CoO -	tr.		tr.		tr.				
ZrO ₂ -								?	.01
Total -	99.91	99.99	100.05	100.75	99.75	99.67	99.65	100.37	100.29
Sp. Gr.	2.427	2.398	2.385	2.433	2.454	2.47	?	2.454	2.428

I.—Obsidianite from near Mt. Elephant, Victoria. Analysed by G. Ampt, 1908.

II.—Obsidianite from near Hamilton, Victoria. Analysed by G. Ampt, 1908.

III.—Obsidianite from Peake Station, near Lake Eyre, South Australia. Analysed by G. Ampt, 1908.

IV.—Obsidianite from between Everard Range and Fraser Range, South Australia. Analysed by C. v. John, 1900. *Jahrb. d.k.k. geol. Reichsanst., Vienna, 1900, Vol. L, p. 238.*

¹ *Journal of Geology*, vol. x., pt. II., 1902.

V.—Obsidianite from near Coölgardie, Western Australia. Analysed by A. Hall, 1907.—Records of the Geol. Survey of Victoria, Vol. II., Part 4, 1908, p. 205.

VI.—Obsidianite from near Kalgoorlie, Western Australia. Analysed by E. S. Simpson, 1902.—West Aust. Geol. Survey. Bulletin No. 6, 1902, p. 79.

VII.—Obsidianite from near Uralla, New South Wales. Analysed by J. C. H. Mingaye, 1897. Proc. Roy. Soc. of Victoria, Vol. XI., N.S., Part I., p. 30.

VIII.—Obsidianite from the Upper Weld, Tasmania. Analysed by W. F. Hillebrand, 1905.—Report of the Secretary for Mines, Tasmania, for 1905, p. 21.

IX.—Obsidianite from Pieman, Tasmania. Analysed by W. F. Hillebrand, 1905.—Report of the Secretary for Mines, Tasmania, for 1905, p. 21.

By dividing the percentages by the molecular weights of the oxides the molecular proportions of the principal constituents are obtained, as under :—

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO ₂ -	1.207	1.271	1.295	1.187	1.177	1.194	1.078	1.163	1.2
Al ₂ O ₃ -	.129	.111	.098	.133	.132	.117	.165	.147	.1
Fe ₂ O ₃ -	.003	.002	.002	.005	.005	.006	.041	.003	.0
FeO -	.062	.054	.052	.074	.062	(.071)	.014	.065	.0
MgO -	.047	.037	.040	.060	.061	.052	.062	.062	.0
CaO -	.057	.046	.043	.063	.055	.054	.069	.057	.0
Na ₂ O -	.025	.020	.021	.024	.021	.028		.021	.0
K ₂ O -	.020	.019	.021	.024	.024	.026	.043	.027	.0
TiO ₂ -	.009	.008	.011		.011			.010	.0
MnO -	.001	.001		.004	.006	.002	.003	.003	.0

The classification of the analysis of the obsidianite from near Mount Elephant may be given as an example of the method used. The molecules in their right proportions are distributed among the "normative" minerals with the following result :—

	Molecular Proportions.	Orthoclase.	Albite.	Anorthite.	Ilmenite.	Magnetite.	Hypersthene.	Corundum.	Quartz.
SiO ₂ -	1.207	120	150	114	-	-	98	-	725
Al ₂ O ₃ -	.129	20	25	57	-	-	-	27	-
Fe ₂ O ₃ -	.003	-	-	-	-	3	-	-	-
FeO -	.062	-	-	-	9	3	50	-	-
MgO -	.047	-	-	-	-	-	47	-	-
CaO -	.057	-	-	57	-	-	-	-	-
Na ₂ O -	.025	-	25	-	-	-	-	-	-
K ₂ O -	.020	20	-	-	-	-	-	-	-
TiO ₂ -	.009	-	-	-	9	-	-	-	-
MnO -	.001	-	-	-	-	-	1	-	-

Reducing the foregoing results to percentages, we obtain the "Norm." or "standard mineral composition."

Mineral.		Norm.
Quartz	= .725 × 60	= 43.5
Orthoclase	= .020 × 556	= 11.1
Albite	= .025 × 524	= 13.1
Anorthite	= .057 × 278	= 15.8
Corundum	= .027 × 102	= 2.8
Hypersthene	= { .047 × 100 } = { .051 × 132 }	= 11.4
Ilmenite	= .009 × 152	= 1.4
Magnetite	= .003 × 232	= .7

The "salic" minerals, i.e., the quartz, felspar and corundum total 86.3, and the "femic" minerals, i.e., the ferro-magnesian minerals and iron oxides total 13.5. In the same way the norms of the other obsidianites may be calculated, the results being as follows:—

NORMS.

MINERALS.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Quartz -	43.5	51.8	52.7	38.4	41.0	38.6	37.2	38.8	46.6
Orthoclase-	11.1	10.6	11.7	13.3	13.4	14.5	23.9	15.0	11.8
Albite -	13.1	10.5	11.0	12.6	11.0	14.7		11.0	8.9
Anorthite	15.8	12.8	12.0	17.5	15.3	15.0	19.2	15.9	18.6
Corundum-	2.8	2.7	1.3	2.3	3.3	.9	5.4	4.3	1.6
Hypersthene	11.4	9.5	9.1	15.6	13.0	14.0	6.2	13.4	10.3
Magnetite-	.7	.5	.4	1.2	1.1	1.4	3.9	.7	.4
Ilmenite -	1.4	1.2	1.7		1.7			1.5	1.4
Hematite -							3.8		

Having calculated the norm., the next step is to classify each analysis. The classification of the analysis of the Mt. Elephant example is obtained in the following manner:—

$$\frac{\text{Sal.}}{\text{Fem.}} = \frac{86.3}{13.5} < \frac{7}{1} > \frac{5}{3} = \text{Class II. Dorsalane}$$

$$\frac{\text{Quartz}}{\text{Felspar}} = \frac{43.5}{40.0} < \frac{5}{3} > \frac{3}{5} = \text{Order III. Quarfelic—Hispanare}$$

$$\frac{\text{K}_2\text{O} + \text{Na}_2\text{O}}{\text{CaO}} = \frac{45}{57} < \frac{5}{3} > \frac{3}{5} = \text{Rang. III. Alkali-calcic—Almerase}$$

$$\frac{\text{K}_2\text{O}}{\text{Na}_2\text{O}} = \frac{20}{25} < \frac{5}{3} > \frac{3}{5} = \text{Sub-rang. III. Sodi-potassic—Almerose}$$

In a similar manner the classification of the other analyses is worked out, and a table is given showing the subdivisions to which each belongs.

No.	CLASS.	ORDER.	RANG.	SUB-RANG.
I.	- II. Dorsalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerase	III. Sodi-potassic Almerose
II.	- I. Persalane	III. Quarfelic Columbare	III. Alkali-calcic Riesenase	III. Sodi-potassic Riesenose
III.	- I. Persalane	III. Quarfelic Columbare	III. Alkali-calcic Riesenase	III. Sodi-potassic Riesenose
IV.	- II. Dorsalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerase	III. Sodi-potassic Almerose
V.	- II. Dorsalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerase	III. Sodi-potassic Almerose
VI.	- II. Dorsalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerase	III. Sodi-potassic Almerose
VII.	- II. Dorsalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerase	I. Perpotassic (Urallaose)
VIII.	II. Dorsalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerose	III. Sodi-potassic Almerose
IX.	- I. Persalane	III. Quarfelic Columbare	III. Alkali-calcic (Piemanase)	III. Sodi-potassic (Piemanose)

To those unacquainted with this system of classification the subdivisinal names can convey no meaning unless the positions of these subdivisions are known, and therefore I include a table of portions of Classes I. and II. The small numbers in brackets indicate the number of high-class analyses of terrestrial igneous

rocks, published by Washington,¹ in each subdivision. Some of the analyses fall into subdivisions, to which no name has been given by the authors of the system, and when this is the case, I have suggested names, chiefly for convenience in reference, and these names have been placed in brackets. In the complete classification there are five classes in all, and Classes I. and II. each have nine orders. All the rangs and sub-rangs into which Orders II., III. and IV. of Classes I. and II. are subdivided, are shown in the tables:—

CLASS I.—PERSALANE.

ORDER	II. BELGARE (13)	III. COLUMBARE (125)	IV. BRITANNARE (378)
RANG.		I. ALASKASE - (47)	I. LIPARASE - (110)
Sub-rang.		i. <i>x</i> (1)	i. Lebachose - (3)
Sub-rang.		ii. Magdeburgose (9)	ii. Omeose - (9)
Sub-rang.		iii. Alaskose - (31)	iii. Liparose - (78)
Sub-rang.		iv. <i>x</i> (3)	iv. Kallerudose - (12)
Sub-rang.		v. Westphalose (3)	v. Noyangose - (8)
RANG.	I DARGASE - - (6)	II. ALSBACHASE - (51)	II. TOSCANASE (191)
Sub-rang.)	i. (<i>Radomilitzose</i>) (2)	i. - - - - -	i. - - - - -
Sub-rang.)	ii. <i>x</i> (2)	ii. Mihalose - (6)	ii. Dellenose - (6)
Sub-rang.)	iii. <i>x</i> (2)	iii. Tehamose - (25)	iii. Toscanose (109)
Sub-rang.)		iv. Alsbachose (16)	iv. Lassenose - (73)
Sub-rang.)		v. Yukonose - (4)	v. Mariposose - (3)
RANG.	II. (MOLDAVASE) (5)	III. RIESENASE (26)	III. COLORADASE - (75)
Sub-rang.)	i. (<i>Moldavose</i>) (3)	i. - - - - -	i. - - - - -
Sub-rang.)	ii. <i>x</i> (1)	ii. <i>x</i> (7)	ii. <i>x</i> (0)
Sub-rang.)	iii. <i>x</i> (1)	iii. <i>Riesenose</i> - (11)	iii. Amiatose - (17)
Sub-rang.)		iv. <i>x</i> (5)	iv. Yellowstonose (56)
Sub-rang.)		v. Vulcanose - (3)	v. Amadorose - (2)
RANG.	III. (BUDWEISASE) (1)	IV. (PIEMANASE) (1)	IV. <i>x</i> (2)
Sub-rang.	i. (<i>Budweisose</i>) (1)	i. <i>x</i> (0)	i. - - - - -
Sub-rang.	ii. - - - - -	ii. (<i>Piemanose</i>) (1)	ii. - - - - -
Sub-rang.	iii. - - - - -	iii. - - - - -	iii. <i>x</i> (2)
RANG.		V. - - - - -	V. - - - - -

NOTE.—An *x* indicates that analyses are known which belong to this division, but that no name is suggested by the authors.

CLASS II.—DOSALANE.

ORDER	II.	(0)	III. HISPANARE	(15)	IV. AUSTRARE	(241)
RANG.			I. VARIOSE	(5)	I. PANTELLARASE	(10)
Sub-rang.			i. - - - -		i. - - - -	
Sub-rang.			ii. - - - -		ii. - - - -	
Sub-rang.			iii. Variose	(4)	iii. GORUDOSE	(6)
Sub-rang.			iv. <i>x</i>	(1)	iv. PANTELLEROSE	(4)
Sub-rang.			v. - - - -		v. - - - -	
RANG.	I.	(4)	II.	(4)	II. DACASE	(40)
Sub-rang.)	i.		i.		i.	
Sub-rang.)			ii. <i>x</i>	(1)	ii. <i>x</i>	(2)
Sub-rang.	ii.		iii. <i>x</i>	(2)	iii. ADAMELLOSE	(19)
Sub-rang.)			iv. <i>x</i>	(1)	iv. DACOSE	(19)
Sub-rang.)	iii.		v. - - - -		v. - - - -	
RANG.	II.	(2)	III. ALMERASE	(2)	III. TONALASE	(155)
Sub-rang.)			i. (<i>Urallaose</i>)	(0)	i. - - - -	
Sub-rang.)	i.		ii. - - - -		ii. <i>x</i>	(3)
Sub-rang.	ii.		iii. <i>Almerose</i>	(1)	iii. HARZOSE	(26)
Sub-rang.)			iv. <i>Sitkose</i>	(1)	iv. TONALOSE	(117)
Sub-rang.)	iii.		v. - - - -		v. PLACEROSE	(9)
RANG.	III.	(3)	IV.	(3)	IV. BANDASE	(36)
Sub-rang.	i.		i. <i>x</i>	(1)	i. SAGAMOSE	(2)
Sub-rang.	ii.		ii. - - - -		ii. <i>x</i>	(8)
Sub-rang.	iii.		iii. <i>x</i>	(2)	iii. BANDOSE	(26)
RANG.		(1)	V. GORDONASE	(1)	V.	

Of the nine analyses quoted five fall into the sub-rang Almerose. In this subdivision Washington gives only one analysis, that of a cordierite andesite from Almeria, in Spain. Eleven analyses are given in sub-rang Riesenose, that to which the obsidianites from Peake Station and Hamilton belong, but (*Urallaose*) is unrepresented and (*Piemanose*) is only represented by a segregation in granite. For the sake of comparison the following analyses are given. They are taken from Washington's tables of analyses. In the first column of each analysis is shown the percentage of each oxide, and in the second column is shown the molecular proportion :—

	I.		II.		III.	
SiO ₂	63.75	1.063	77.27	1.288	68.87	1.148
Al ₂ O ₃	17.62	.173	9.98	.098	16.42	.161
Fe ₂ O ₃	3.00	.019	2.58	.016	1.91	.012
FeO	3.26	.045	.41	.005	2.06	.029
MgO	3.41	.085	.51	.013	2.54	.064
CaO	2.50	.045	2.28	.041	4.64	.083
Na ₂ O	1.75	.030	2.14	.034	1.25	.020
K ₂ O	2.40	.025	2.39	.024	1.10	.012
TiO ₂			tr.			
MnO			.99	.014		
H ₂ O	2.77		.86		1.12	
Total	100.45		99.41		99.91	

I.—Almerose. Cordierite andesite, Hoyazo, Cabo de Gata, Almeria, Spain.

II.—Riesnose. Granite, Wengenweise, Henweg, Hesse.

III.—(Piemnose). Schliere in granite, Vorderberg, Riesengebirge, Silesia.

The norms for these rocks are:—

	I.	II.	III.
Quartz	31.9	50.6	42.5
Orthoclase	13.9	13.9	6.7
Albite	15.7	17.8	10.5
Anorthite	12.5	10.8	23.1
Corundum	7.4	.3	4.7
Hypersthene	12.0	1.3	8.6
Magnetite	4.4	1.2	2.8
Hematite		1.7	

As a result of the classification of the analyses of obsidianites, we are now in a position to compare these analyses critically with one another, and also with other analyses. It is self-evident that there is a strong family resemblance between all nine analyses. Most of the obsidianites, as already stated, belong to the group Almerose, and the others do not diverge greatly from this type. The subdivision Riesnose, though belonging to a higher class than Almerose, still falls into the corresponding Order, Rang and Sub-rang, the only difference being that the higher percentage of silica and lower percentage

of magnesia and iron cause the total of the silic minerals in this case to be more than seven times the ferric minerals.

The Uralla analysis corresponds closely to the other analyses, and would fall into the group Almerose, but for the almost entire absence of soda. It will be seen that the total alkalis are about normal, and it is to be hoped that more analyses of buttons from this area may be made to determine if this result be in accord with others from the same locality.

The analyses of the specimen from Pieman wanders farthest from the type group. The large excess of lime over the alkalis throws this analysis into Rang IV., otherwise it is fairly closely related to Riesenose.

The division line between Class I. and Class II. is necessarily an arbitrary one, so that with an increase in the number of analyses of obsidianites we should probably get a perfect gradation from Riesenose to Almerose. Even as it is we see that some of the analyses belonging to the Almerose Sub-rang seem to be more nearly related to the analysis of the Hamilton specimen than to other analyses falling into the same group as themselves.

By far the most important result of the classification of the analyses is, however, to demonstrate clearly that rocks having compositions similar to those of the obsidianites are rarely met with among the igneous rocks of the earth's surface. The importance of this result becomes very evident when we come to consider the origin of the obsidianites.

THE ORIGIN OF OBSIDIANITES.

Several hypotheses have been advanced to account for the origin and distribution of obsidianites, and naturally their chemical composition has an important bearing on the solution of the problem. It has been stated:—

- (a) They are artificial products.
- (b) They represent a peculiar form of volcanic ejectamenta.
- (c) They are meteoritic in origin.

(a) *Artificial Products.*—

At first sight the general appearance of obsidianites may incline one to the belief that they are artificial in origin, but a

consideration of the chemical composition shows that such a belief is untenable. The analyses show that if the obsidianites be artificial, they must have come from a common source, and are either the result of the melting down of some substance having the requisite chemical composition, or else are the products of high-class metallurgical works. The occurrence of the buttons over such a large area shows that the distribution from this common source must have commenced long before the discovery of Australia, so that to believe in the artificial origin of obsidianites we must believe that among the Australian aborigines were first-class metallurgical chemists who had control of temperatures of over 1300 deg. C.

(b) *Volcanic Products.*—

Most of the earlier writers on this subject believed that the obsidianites were a peculiar form of volcanic bomb, and this opinion is still held by many. Various places, such as the volcanoes of New Zealand, South Victoria Land, and the Malay Archipelago, and the extinct volcanoes of Victoria, have been named as the source from which the bombs were derived. Unfortunately, no reliable analyses of Victorian basalts have been recorded, but analyses of rocks from the other areas are given below, together with the analyses of the Coolgardie obsidianite for convenience in comparison. Only the more important constituents are quoted.

	I.	II.	III.	IV.
SiO ₂ -	70.62	75.46	68.51	57.95
Al ₂ O ₃ -	13.48	11.27	15.96	20.43
Fe ₂ O ₃ -	.85	1.17	2.61	3.43
FeO -	4.44	2.05	1.09	1.35
MgO -	2.42	.27	1.07	.26
CaO -	3.09	.53	3.14	1.90
Na ₂ O -	1.27	3.45	4.01	8.32
K ₂ O -	2.22	4.88	1.82	5.96
H ₂ O + -	.01	.28	n. d.	.39
H ₂ O - -	.06	.07	-	.23
TiO ₂ -	.90	.05	.82	.40
MnO -	.42	tr.	.28	.07
Total -	99.75	99.93	100.65	100.76
Sp. Gr.	2.454	2.353	2.329	?

I.—Obsidianite from near Coolgardie, Western Australia.

II.—Obsidian from Mayer's Island, New Zealand. Analysed by P. G. W. Bayly.—Records of the Geol. Survey of Victoria, Vol. II., Part 4, 1908, p. 205.

III.—Andesitic Pumice from Krakatoa Eruption, 1883. Analysed by C. Winkler. Washington, Chemical Analyses of Igneous Rocks, p. 193.

IV.—Phonolitic Trachyte from top of 900 ft. knoll, Mt. Terror, South Victoria Land. National Antarctic Expedition, 1901-1904. Natural History, Vol I., Geology, pp. 114, 119.

The norms corresponding to these analyses are:—

	I.	II.	III.	IV.
Quartz - -	41.0 -	35.5 -	29.9 -	
Orthoclase - -	13.4 -	29.0 -	11.1 -	35.0
Albite - -	11.0 -	29.3 -	33.5 -	36.0
Anorthite	15.3 -	.6 -	15.6 -	.8
Nephelite - -	-	-	-	18.5
Corundum - -	3.3 -	-	1.6 -	-
Diopside - -	-	1.7 -	-	1.5
Hypersthene -	13.0 -	2.5 -	2.7 -	-
Wollastonite -	-	-	-	2.8
Magnetite - -	1.1 -	1.6 -	1.2 -	3.5
Ilmenite - -	1.7 -	0.2 -	1.5 -	.8
Hematite - -	-	-	1.7 -	1.0

From these results we obtain the following classification:—

CLASS.	ORDER.	RANG.	SUB-RANG.
I.—II. Dosalane	III. Quarfelic Hispanare	III. Alkali-calcic Almerase	III. Sodi-potass Almerose
II.— I. Persalane	III. Quarfelic Columbare	I. Peralkalic Alaskase	III. Sodi-potass Alaskose
III.— I. Persalane	IV. Quardefelic Brittanare	III. Alkali-calcic Coloradase	IV. Dosodic Yellowstonos
IV.— I. Persalane	VI. Lendofelic Russare	I. Peralkalic Miaskase	IV. Dosodic Miaskose

The analysis of the New Zealand obsidian is that of a fairly normal acid glass, in which the sum of the alkalis very greatly exceeds the lime. Other analyses of New Zealand rhyolitic rocks quoted by Washington are found to be closely related to that of the Mayer Is. specimen.

All the analyses of acid and intermediate rocks from South Victoria Land recorded by Dr. Prior are found to be closely related to one another, and the analysis quoted may be taken as fairly representative.

Very few analyses of recent volcanic rocks from the Malay Archipelago are recorded, the one given above being the only superior analysis of material from this area, quoted by Washington.

An examination of the foregoing results should prove conclusively that there is no chemical relationship between the obsidianites and the rocks quoted, and therefore the chemical evidence at present available is entirely opposed to the possibility of New Zealand, South Victoria Land or Malay Archipelago being the sources of the obsidianites.

Although no reliable analyses of Victoria basalts have been recorded, numerous micro-sections have been examined, and there is no evidence of any departure from a normal composition, and as they are all basic in character, the obsidianites cannot possibly be glassy representatives of these rocks. Mr. Dunn¹ suggests that the obsidianites may have preceded the basaltic flows, but this is impossible in some cases, as the buttons are often found resting on the surface of the lava flows. In some areas it has been shown¹ that a gradual change has taken place in the composition of the lava poured out by the volcanoes of that area, the result being that whereas the earliest flows were basaltic, the final products were more closely allied to obsidian.

Even if we disregard the almost unique composition of the obsidianites, we are not justified in assuming that they represent any such acid residuum from a basic magma, for if acid differentiation products were formed we should certainly find some traces of them in or around some of the extinct cones.

It would seem, therefore, that the advocates of a volcanic origin for the obsidianites receive no support from a consideration of their chemical composition.

¹ Records of the Geol. Survey of Victoria, vol. ii., pt. IV., 1908, p. 204.

¹ Geikie's Text Book of Geology, pp. 137, 349, 708.

(c) *Meteoritic Origin.*—

Before discussing what bearing the chemical composition of the obsidianites has to the meteoritic hypothesis of their origin, some account of their distribution from a chemical standpoint is necessary.

Referring back to the table of analyses, it will be seen that the specific gravity practically varies inversely as the percentage of silica. By determining the specific gravity of a specimen, therefore, we have a quick method of arriving at its approximate composition. On receiving Mr. Ampt's analysis of the Peake Station obsidianite, I was struck by the extremely low specific gravity (2.385) of this specimen, no other recorded determination being less than 2.41. I therefore set to work to carefully determine the gravity of some of the specimens at my disposal. All buttons were carefully cleaned and scrubbed with dilute hydrochloric acid, and after being washed and dried, were weighed on a chemical balance. They were then boiled in distilled water to get rid of every trace of surface air bubble, and on cooling were re-weighed in water. Six determinations were made of buttons from Hamilton, from Balmoral, and from Peake Station. The results are given below, together with six specific gravities recorded by Mr. Simpson of obsidianites from Kalgoorlie.

	I.	II.	III.	IV.
1.	2.395	2.389	2.376	2.43
2.	2.398	2.401	2.376	2.43
3.	2.401	2.401	2.389	2.45
4.	2.401	2.406	2.406	2.45
5.	2.401	2.413	2.414	2.46
6.	2.406	2.455	2.436	2.49

I.—Six small specimens from near Hamilton.

II.—Six small specimens from Balmoral.

III.—Six large specimens from Lake Eyre District.

IV.—Six specimens from Kalgoorlie.

Mr. Kerr Grant determined the bulk specific gravity of sixty-nine specimens from the Lake Eyre District, and kindly furnished me with the result obtained, viz., 2.395.

The above results are extremely interesting, as they point to

a certain amount of provincial distribution of the obsidianites. It will be seen that the average specific gravity of the Hamilton specimens is 2.400, and Mr. Simpson gives 2.448 as the average specific gravity of the specimens determined by him. Judging from the above values, it seems that the Lake Eyre District and Western Victoria are characterised by a more acid type of obsidianite than Kalgoorlie District.

For convenience in recording the distribution of the different types, I would suggest the following divisions, according to specific gravity:—

A.—Under 2.390. Peake Station type. Analysis No. III.

B.—2.391—2.410. Hamilton type. Analysis No. II.

C.—2.411—2.440. Mt. Elephant type.¹ Analysis No. I.

D.—2.441—2.470. Kalgoorlie type. Analyses Nos. IV., V., VI., VIII.

E.—Over 2.470. (?) type.² No analysis.

The gravities recorded in this paper give the following results:—

Hamilton	6B.
Balmoral	1A, 3B, 1C, 1D.
Peake Station	3A, 1B, 2C.
Kalgoorlie	2C, 3D, 1E.

I hope in time to collect a sufficient number of records of specific gravities to thoroughly test this apparent distribution according to chemical composition.

Judging from records taken from Mr. Walcott's paper, viz., Clarke, 2.42—2.7; Stelzner, 2.41—2.52; Twelvetrees and Petterd, 2.45—2.47; and Walcott, 2.42—2.48, it seems that the Peake Station and Hamilton types are rarely met with, except in the type localities. As, however, these are the prevailing types about Lake Eyre and part of Western Victoria, it appears that we certainly have two areas on which the more acid type fell most abundantly, whereas about Kalgoorlie nothing but the more basic types are recorded.

1 The Mt. Elephant analysis is taken as the standard as it is more normal than the Pieman analysis.

2 The Uralla specimen may belong here, but unfortunately no specific gravity is recorded.

What little evidence we have, therefore, strongly supports this idea of provincial distribution, and if on further work this is upheld, the cosmic origin of obsidianites is practically determined, because such distribution is impossible by means of any of the agencies suggested by the advocates of a volcanic or artificial origin. The agencies which have been suggested are water, ice, aborigines, birds, winds, volcanic explosions and hypothetical bubbles. It is quite inconceivable that chemical distribution could be effected by any of these means.

The two principal arguments against the meteoritic hypothesis are—the form and the composition of the obsidianites. This paper is only concerned with the latter. It has been argued that obsidianites cannot be meteoritic in origin, because they differ so completely in composition from all known meteorites. The stony meteorites are all extremely basic in composition. This argument cuts both ways, however, for we may with quite as much justification say that as the obsidianites do not agree in composition with terrestrial rocks, they are therefore extra-terrestrial.

As the artificial origin is impossible, and as none of the suggested volcanic sources have produced lavas at all agreeing in composition with that of obsidianites, these two hypotheses appear untenable. This leaves us the meteoritic hypothesis, and the almost unique composition of the obsidianites, together with their apparent provincial distribution, makes it practically certain that this is the correct explanation of the origin of these interesting substances.

BILLITONITES AND MOLDAVITES.

Dr. Suess¹ quotes three analyses of billitonites, but only two are sufficiently complete for purposes of classification. The analyses, with their molecular proportions, are as follows:—

¹ Die Herkunft der Moldavite und verwandter Glaser. Jahrb. d. k. k. geol. Reichsanst. Vienna, 1900, vol. 50.

	I.			II.	
SiO ₂	70.92	1.182	-	71.14	1.186
Al ₂ O ₃	12.20	.120	-	11.99	.117
Fe ₂ O ₃	1.07	.007	-		
FeO	5.42	.075	-	5.29	.073
MgO	2.61	.065	-	2.38	.059
CaO	3.78	.068	-	2.84	.051
Na ₂ O	2.46	.040	-	2.45	.039
K ₂ O	2.49	.027	-	2.76	.029
MnO	.14	.002	-	.32	.005
Total	101.09			99.17	
Sp. Gr.	2.447			2.43	

I.—Billitonite from Tebrung, Dendang. Analysed by C. v. John.

II.—Billitonite from Lara Mijn, No. 13, Dendang. Analysed by Dr. Brunck.

The following are the norms calculated from these analyses:—

	I.	II.
Quartz	31.4	32.0
Orthoclase	15.0	16.1
Albite	21.0	21.0
Anorthite	14.7	13.6
Diopside	3.4	.7
Hypersthene	14.0	15.8
Magnetite	1.6	-

Both of these analyses fall into the sub-rang. Almerose, and although differing somewhat from the obsidianites which fall into this group the general resemblance is very marked.

Six analyses, quoted by Dr. Suess, of Moldavites are capable of classification. All these analyses were made by C. v. John, Vienna.

	I.	II.	III.	IV.	V.	VI.
SiO ₂	77.69	82.28	77.75	77.96	82.68	78.61
Al ₂ O ₃	12.78	10.08	12.90	12.20	9.56	12.01
Fe ₂ O ₃	2.05			.14		.16
FeO	1.45	2.03	2.60	3.36	1.13	3.06
MgO	1.15	.98	.22	1.48	1.52	1.29
CaO	1.26	2.24	3.05	1.94	2.06	1.62
Na ₂ O	.78	.28	.26	.61	.63	.44
K ₂ O	2.78	2.20	2.58	2.70	2.28	3.06
MnO				.10	.18	.11
Loss on ignition		.06	.10			
Total	99.94	100.15	99.46	100.49	100.04	100.49

- I.—Moldavite from Radomilitz, near Budweis (Light brown).
 II.—Moldavite from Radomilitz, near Budweis (Light green).
 III.—Moldavite from Radomilitz, near Budweis (Dark green).
 IV.—Moldavite from Tribitsch.
 V.—Moldavite from Budweis (Light green).
 VI.—Moldavite from Tribitsch.

The norms. are as follow :—

	I.	II.	III.	IV.	V.	VI.
Quartz - -	57.3	63.8	57.5	54.6	62.6	56.8
Orthoclase - -	16.7	13.3	15.0	16.1	13.3	17.2
Albite - -	6.8	2.6	2.1	5.2	5.2	3.7
Anorthite - -	6.4	11.1	15.3	9.9	10.3	8.1
Corundum - -	6.0	3.1	4.0	4.7	2.3	5.2
Hypersthene - -	3.8	6.2	5.4	10.0	6.3	9.3
Magnetite - -	3.0			.2		.2

The sub-rangs. into which these analyses fall are :—

- I.—(Radomilitzose).
 II.—(Moldavose).
 III.—(Budweisose).
 IV.—(Moldavose).
 V.—(Moldavose).
 VI.—(Moldavose).

It will be seen that the composition of the moldavites differs considerably from that of the obsidianites. In this case, again, we have almost unique compositions such as are rarely met with among the igneous rocks of the earth. Dr. Suess strongly upholds the cosmic origin of these bodies, and also of the billitonites and australites=obsidianites.

Summary and Conclusions.

Six recorded and three new analyses of obsidianites are brought together and compared by means of the American classification of igneous rocks.

It is shown that the analyses indicate compositions rarely met with among terrestrial rocks.

The artificial origin of obsidianites is shown to be chemically impossible.

Analyses of rocks from the various places named as possible sources of the obsidianites, are compared with the analyses of the obsidianites and it is shown that there is nothing in common between them.

It is pointed out that there is an apparent provincial distribution of obsidianites, and if this is proved to be correct, it is shown that a cosmic origin is the only possible one.

Analyses of billitonites are given and classified, and shown to be genetically connected with the obsidianites.

Six analyses of moldavites, when classified, are found to have few representatives among terrestrial rocks, and the argument in favour of a cosmic origin for them is strengthened.

APPENDIX.

The following additional information has come to hand since the above paper was read:—

New Zealand.—In answer to a letter inquiring about the occurrence of obsidianites in New Zealand, Dr. Marshall wrote:—"I think I can say without any qualification that there is no record whatever of the occurrence of such objects in New Zealand. Of course you are aware that obsidian, as a rock, occurs at many localities, notably at Mayor Island, Rotorua, and near Whangaroa, but even in these districts I have seen no obsidian bombs, to say nothing of obsidianites."

Queensland.—Mr. Dunstan, Government Geologist of Queensland, informed me that they had often inquired about the occurrence of obsidian bombs in Queensland, but could get no specimens, and, further, had not heard of any being found.

New South Wales.—Mr. Card called my attention to the record of obsidianites in the Records of the Geological Survey of New South Wales, Vol. VII., Pt. III., p. 218. Four specimens are figured. At the same time he told me that Mr. Mingaye was not satisfied with the analysis of the Uralla obsidianite, as he had very little material to work on, and intended analysing another specimen from the same locality.

South-Western New South Wales.—The following is the record of the specific gravities of twenty obsidianites obtained by Mr Milo R. Cudmore, from a station situated 185 miles north-west of Wentworth, New South Wales, and 120 miles east of Kooringa, South Australia:—

2.439	-	2.421	-	2.417	-	2.408
2.439	-	2.419	-	2.415	-	2.407
2.433	-	2.419	-	2.415	-	2.401
2.432	-	2.419	-	2.415	-	2.391
2.431	-	2.418	-	2.414	-	2.389

Average specific gravity—2.417.

Tasmania.—Mr. W. F. Pettard has kindly forwarded me a pamphlet on the minerals of Tasmania, prepared for the use of the members of the Australasian Association for the Advancement of Science, during the last meeting in Tasmania. In this Mr. Pettard states that he is of opinion that a meteoritic shower of obsidianites occurred in post-pliocene time, which impinged upon the earth in a north-western track, crudely extending from Tasmania to Victoria, from thence to the northern part of West Australia, and thence to the western islands of the Malay Archipelago.

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For record of earlier Literature, reference should be made to the papers by Mr. R. H. Walcott and Dr. Suess.
